DOI: 10.17650/1683-3295-2021-23-2-128-133

CEREBROVASCULAR ANEURYSM CLIPPING TRAINING MODELS WITH PULSATILE BLOOD FLOW

M.J. Encarnacion Ramirez

RUDN University; 6 Miklukho-Maklaya St., Moscow 117198, Russia

Contacts: Manuel de Jesus Encarnacion Ramirez dr.encarnacionramirez@hotmail.com

Introduction. Neurosurgery trainees are finding it increasingly difficult to obtain operative experience as the main surgeon in aneurysm procedure. Good quality cadaver dissection opportunities are also not widely available for neurosurgery residents. Simulation is emerging as a useful training aid for neurosurgery. Surgical treatment of cerebral aneurysms requires specialized skills development and proficient use of microsurgical instruments. Furthermore, any advance in neurosurgical training methods is of potential value to both neurosurgeons and patients.

The study objective is to introduce a 3D aneurysm clipping training model to enhance skill acquisition and development.

Materials and methods. The brain model is made using a 3D printed resin mold. The mold is filled with silicone Ecoflex 00–10 and mix with Silc Pig pigment additives to replicate the color and consistency of brain tissue. Dura is made from quick drying silicone paste with grey dye. The blood vessels are made from a silicone 3D printed mold of a magnetic resonance angiography. Liquid with paprika oleoresin (E160c) dye is used to simulate blood and is pumped through the vessels to simulate pulsatile motion.

Results and conclusion. These models offer an alternative method to train residents and preoperative planning. They are affordable and easy to recreate and hence can standardize training in multiple centers. With advancing technology, 3D technology is becoming an import part of medical education.

Key words: 3D model in neurosurgery, aneurysm clipping, neurosurgery training

For citation: Encarnacion Ramirez M.J. Cerebrovascular aneurysm clipping training models with pulsatile blood flow. Neyrokhirurgiya = Russian Journal of Neurosurgery 2021;23(2):128–33. DOI: 10.17650/1683-3295-2021-23-2-128-133.

Применение моделей с имитацией пульсирующего кровотока в обучении клипированию аневризм сосудов головного мозга

М.Х. Энкарнасьон Рамирес

ФГАОУ ВО «Российский университет дружбы народов»; Россия, 117198 Москва, ул. Миклухо-Маклая, 6

Контакты: Мануэль де Хесус Энкарнасьон Рамирес dr.encarnacionramirez@hotmail.com

Введение. Нейрохирургам-стажерам становится все труднее получить опыт проведения вмешательств на аневризмах в качестве оперирующего хирурга. Вскрытие трупов также не всегда возможно. В связи с этим все чаще используются учебные модели. Хирургическое лечение аневризм сосудов головного мозга требует развития специальных навыков и умелого использования микрохирургических инструментов. При этом любое совершенствование методов обучения нейрохирургическим навыкам имеет потенциальную ценность для нейрохирургов и для пациентов.

Цель исследования – внедрить обучающую 3D-модель для приобретения и закрепления навыков клипирования аневризм.

Материалы и методы. Модель мозга изготовлена с использованием 3D-печатной формы из смолы. Форма заполняется силиконом Ecoflex 00–10 и смешивается с пигментами Silc Pig для воспроизведения цвета и консистенции мозговой ткани. Твердая мозговая оболочка изготовлена из быстросохнущей силиконовой пасты с серым красителем, кровеносные сосуды изготовлены из силикона с помощью напечатанной на 3D-принтере формы, воспроизводящей результат магнитно-резонансной ангиографии. Жидкость с красителем (экстрактом паприки E160c) используется для имитации крови и прокачивается по сосудам для имитации пульсирующего движения.

Результаты и заключение. Эти модели позволяют проводить обучение стажеров и планировать операции. Они сравнительно дешевы и легко воссоздаются, а следовательно, могут стандартизировать обучение в нескольких центрах. 3D-технологии по мере их развития становятся важной частью медицинского образования.

Ключевые слова: 3D-модели в нейрохирургии, клипирование аневризмы, обучение нейрохирургов

Для цитирования: Энкарнасьон Рамирес М.Х. Применение моделей с имитацией пульсирующего кровотока в обучении клипированию аневризм сосудов головного мозга. Нейрохирургия 2021;23(2):128–33. (На англ.). DOI: 10.17650/1683-3295-2021-23-2-128-133.

BACKGROUND

Intracranial aneurysm with and without subarachnoid hemorrhage (SAH) is an important health problem: the overall incidence rate is about 9–20 per 100,000 in some countries [1]. Microsurgical clipping is the standard technique for cerebral aneurysm surgery, and a suitable operative plan is the key for a successful operation [2, 3]. Preoperative imaging cannot clearly show the complex anatomical relationship between the aneurysm and the surrounding cranial nerves, vasculature, and other critical anatomical structures. The development of three-dimensional (3D) printing technologies provides a new method for surgical treatment of aneurysm. This technology has been widely used in oral surgery and orthopedics [4], but currently there are few reports on its application in the treatment of aneurysm. Using simulators for surgical training allows residents to develop the necessary motor skills safely and realistically, improving the impact on patient care [5].

We designed a method for developing a three-dimensional hollow and low-cost elastic aneurysm model, useful for surgical simulation and training. In this article, we explain the hollow elastic model with pulsatile blood flow and report on the effects of applying it to presurgical simulation and surgical training. Special efforts were taken to make it easily reproduced by any department of Neurosurgery worldwide.

MATERIALS AND METHODS

Brain model. The brain model development method, is as follows: Obtaining any copy of brain but always keeping in mind a 1:1 scale, it can be a plastic model or a 3D printed one. The problem with making the model with the 3D printer is that the printing is done in layers of 0.2 mm, and we need a model smooth, in that case we can use a resin printer with which we will have a completely smooth model.

In another case we can use a human brain, for which the first thing is that it has a normal morphology without structural pathologies that alter its normal anatomy. It must be dry on its entire surface, which will be in contact with the silicone. We must keep in mind that the brain should be dried, without getting dehydrated to avoid altering its normal anatomy (fig. 1).

Fig. 1. *The brain arachnoid and vessels of the brain are removed and cut in the midline, so as to gain access to the ventricular system, getting to form a negative mold of them*

We used a plastic container or cardboard, allowing a space of approximately 2–3 cm between the brain and the edges of the container. The container will be filled with silicone, in this case we used silicone Tool Decor 25 (Tooldecor 25) – **heat-resistant silicone for casting** where the brain was imbibed and wait for cure time. The next step consists on removing the brain after its cure giving us a negative silicone mold of the brain. The negative piece is filled with silicone Ecoflex 00–10 and mixed with Silc Pig pigment additives in the color Flesh Tone and White (PMS White) to replicate the color and consistency of brain tissue. Then we wait the cure time and remove it (fig. 2).

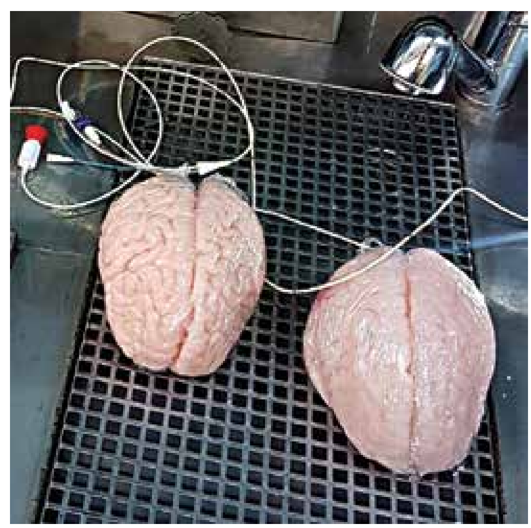

Fig. 2. *Both hemispheres are joined by corpus callosum with silicone*

Meninges model. To simulate the dura mater, we use the silicone copy paste quick-drying, applied with a brush on the entire inner surface of the skull combined with grey polymer "O" PO-MIX 622.2–1 RAL 7040 dye to simulate the dura mater and its color (fig. 3).

Arachnoid. Arachnoid was created with self-adhesive, transparent PVC Flex paper. This method allows a difference in consistency between materials, making it not adherent to the silicone. Its low cost, easy acquisition and similarity with arachnoids make it the best option for us (fig. 4).

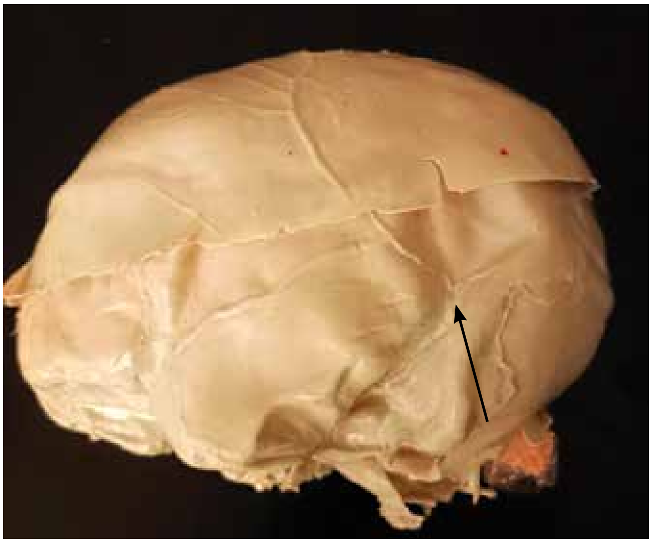

Fig. 3. *The brain with its dura mater is appreciated. The arrow shows the relief caused by the middle meningeal artery*

Fig. 4. *The Sylvian fissure and the insular lobe on its depth*

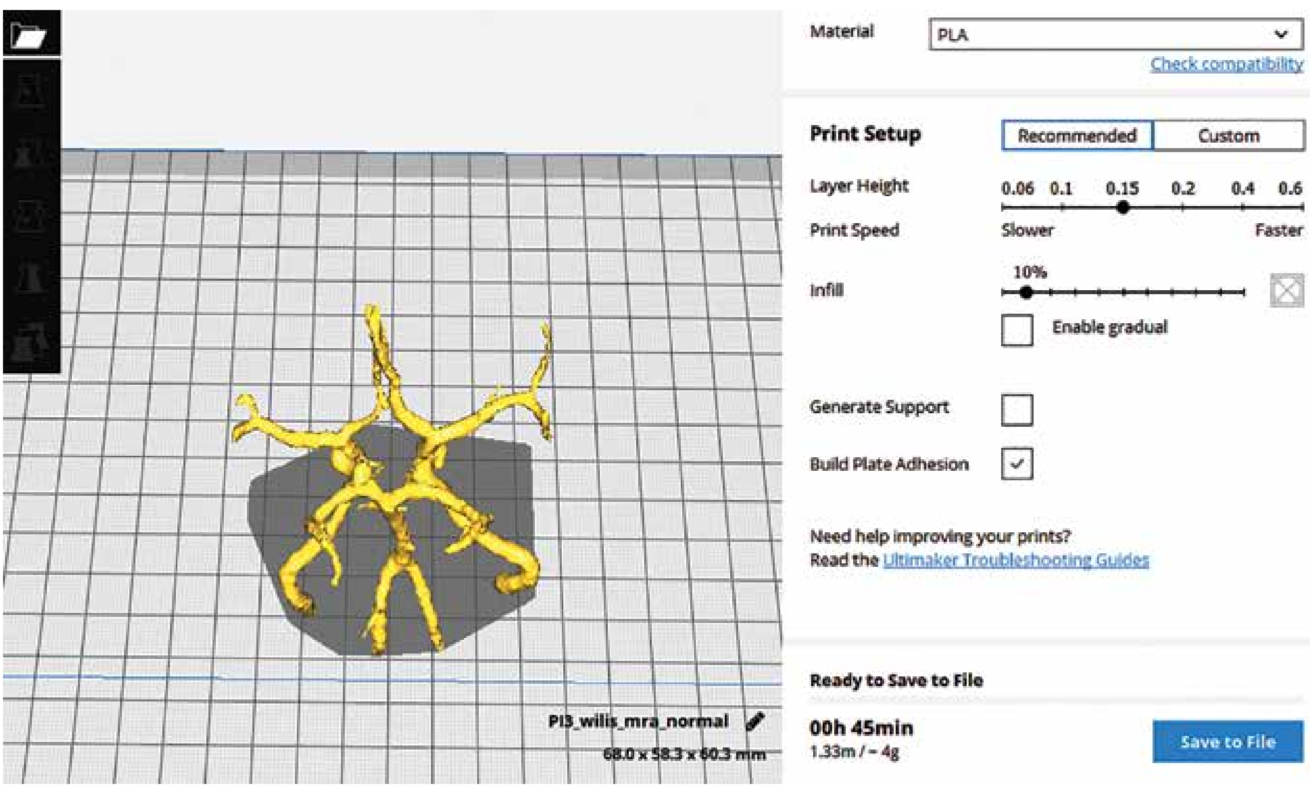

Fig. 5. *We converted the file from DICOM to STL to be printed, the file used to be printed is Ultimaker Cure 3.2.1*

Pia mater. The pia mater is made with a layer of silicone tool decorator 15.

Vessels. We used the angiography of a patient after informed consent of its potential use to be given to our study. We extracted the volumetric from DICOM (Digital Imaging and Communications in Medicine) files, and chose the segment we decided to use of cerebral circulation, leaving only the main vessels (fig. 5).

The vasculature surface model was edited at the clinical workstation to remove rendering artifacts and crop any undesired vessels from the model (fig. 6).

The vessel model now covered with silicone is cut along the length of the vessels to remove the frame. The cut edges of the now hollow vascular structure are sealed with silicone creating tubular models without leaks. These represent normal vessels. The aneurysmal bulges of different

Showing the dimensions of the vessels made and the materials used

Lumen	PLA Model			Silicone model		
	Computational mesh diameter, mm	Physical model diameter, mm	Percentage difference, %	Computational mesh diameter, mm	Physical percentage difference	% model diameter
A anterior cerebral artery	1.95	2.68	31.5	1.95	2.72	32.9
Middle cerebral artery	2.43	2.86	16.2	2.86	2.59	9.9
Internal carotid artery	5.42	6.00	10.15	5.42	6.19	13.26

sizes are created manually using a 0.5-inch pencil 3D printer (table).

In our model, we created aneurysms of the middle cerebral artery on which bypass surgery was simulated. The time of preparation of blood vessels is from 9 to 11 hours.

Percentage difference between the relationship of the glasses at the time of being printed in 3D with the original material, and the relationship of the same glasses with the silicone models in the final result.

RESULTS

Phantom Testing. A pulsating pump and liquid dyed is then implemented into the blood flow model. In our case we use liquid with dye paprika oleoresin (E160c), since the vessels are translucent it is easy to check if there is circulation and see if there is any obstruction or rupture. This dye does not adhere to silicone and does not stain the lumen, therefore, avoiding the vessels appearance change (fig. 7).

The model, all pieces together. After the dura mater is opened, and the Sylvian fissure split, the middle cerebral artery aneurysm dome can be appreciated (which was artificially created for practical purposes) (fig. 8).

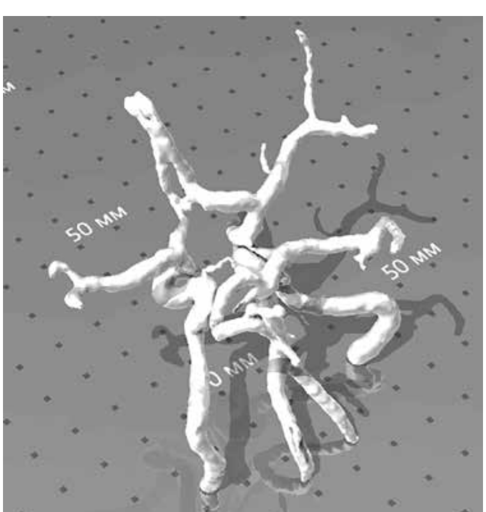

Fig. 6. *After the model has been printed on a basic 3D printer with flexible filament, two layers of silicone (Tool Decor 25) are applied*

Fig. 7. *The complete model in the operating room. The red fluid is being pumped through the vessels*

DISCUSSION

The increasing use of endovascular techniques for the management of aneurysms and other vascular pathologies has left a void in the training of neurovascular surgeons [6]. For example, in a study done in Australia, L. Lai and M.K. Morgan found that there was significant reduction in the exposure of neurosurgeons to open aneurysm interventions. Most neurosurgeons spent less than 5 % of their practice performing aneurysm surgery. The authors saw it reasonable to propose that competence will continue to decline until measure are taken to actively change the patterns of practice and education [7]. Neurovascular surgery is a very delicate field requiring immense focus and very accurate decisive steps and excellent skills which can only be acquired through repeated practice [6]. The operating room is an unforgiving environment where mistakes cause loss of life [8]. Simulations has in the recent past become invaluable in the training of high stake areas like aviation, surgery etc. where failures can have disastrous consequences. The true benefit of simulation based training is to provide a safe environment where training are allowed to make mistakes, perfect skills, refine techniques and avoid costly mistakes [5, 6].

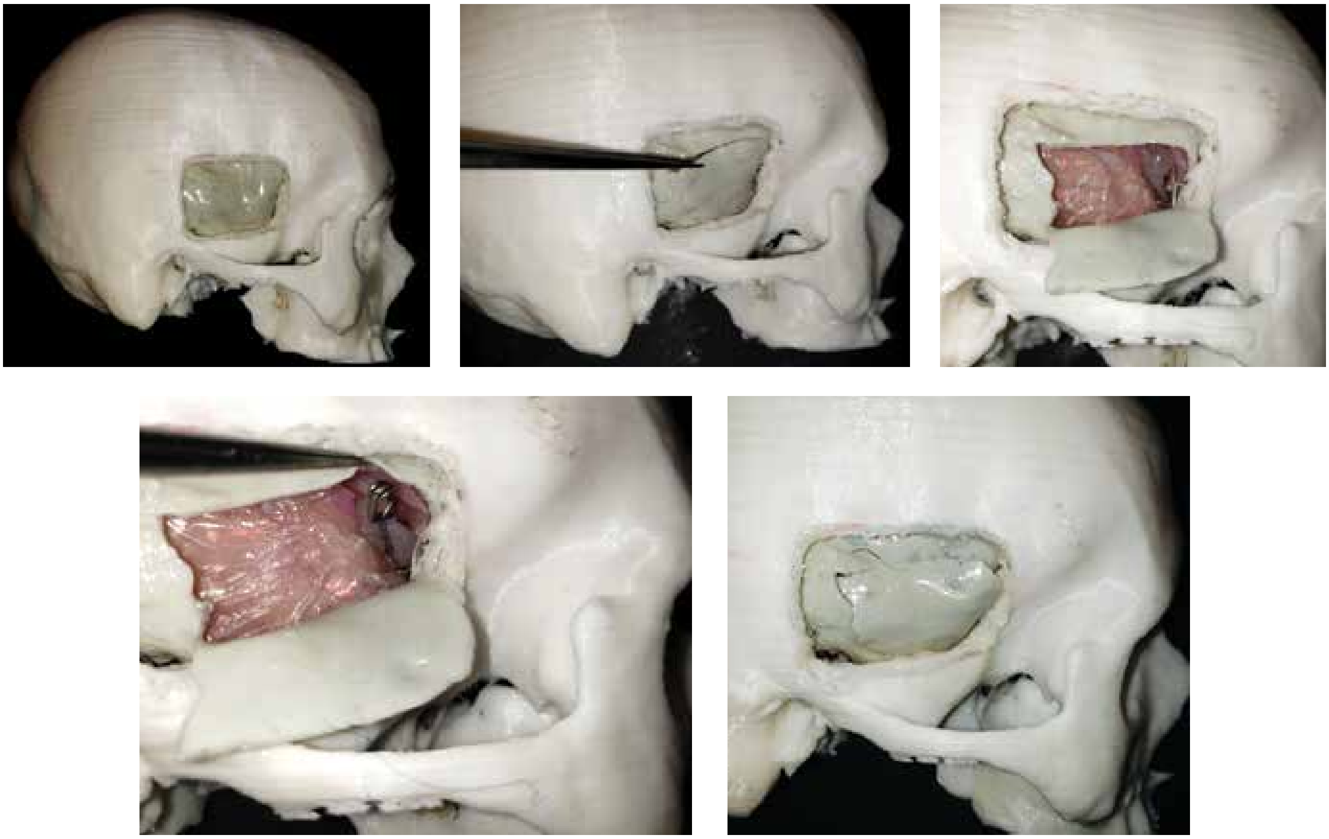

Fig. 8. *Stages of a standard middle cerebral artery aneurysm clipping procedure via pterional craniotomy using the model*

The best surgical training model is the cadaver as it gives the best anatomical picture and feeling. However, not all training centers are able to easily acquire the cadavers in view of the associated costs and legal procedures. Cadaver treatment and storage also require a highly specialized center. 3D models made from various materials are cost effective, some reusable and easily replicable. Many models have been developed for neurovascular simulation. E. Aboud et al. used red fluid to simulate pulsatile blood flow in a cadaveric head [9]. Many other models including placental vessels, chicken wings, rat have been used. However, a good model is one that comes closest to the real anatomy. Our model offers a pulsatile blood flow and expansile main vessels and artificially made aneurysms in a resin or silicone-based brain and skull model. This gives the best anatomical navigation as expected in real surgery.

The 3D models have an added advantage as they can used preoperatively to simulate the actual pathology printed with similar surrounding anatomy to guide surgical plan and anticipate challenges [4]. T. Mashiko et al., used 3D hollow tubes models to simulate aneurysms preoperatively. These models helped them choose the clip sizes accurately and practice clip positioning preoperatively [10].

Although being cheaper and safe than a cadaver, our model still lacks the idea texture of the fresh cadaver and the intricate anatomy. in order to recreate these models a center will need a good quality 3D printer and various types of silicone and resin which some centers do not have. A center will also need to have access to computed tomography scan or magnetic resonance images and programs to transfer data to a 3D printer for processing. Some steps in the creation of the models are difficult and would require someone will experience. However, with experience these models are easily replicable and a possible game changer in the neurovascular training programs.

There remains room for improvement with advancing technology. The use of state-of-the-art 3D printer is a huge determinant for the quality of the models. We continue searching for the best material to match the real brain and vessel texture as close as possible.

CONCLUSION

The void in open neurovascular surgery training is getting wider with increased use of endovascular techniques. However, very few centers especially in developing countries have endovascular services. These models will bridge the gap and standardize the training by increasing exposure to neurovascular hands on scenarios and simulations.

ЛИТЕРАТУРА / REFERENCES

1. Steiner T., Juvela S., Unterberg A. et al. European Stroke Organization guidelines for the management of intracranial aneurysms and subarachnoid haemorrhage. Cerebrovasc Dis 2013;35(2):93–112. DOI: 10.1159/000346087.
2. Fischer G., Stadie A., Reisch R. et al. The keyhole concept in aneurysm surgery: results of the past 20 years. Neurosurgery 2011;68:45–51. DOI: 10.1227/NEU.0b013e31820934ca.
3. Reisch R., Stadie A., Kockro R.A., Hopf N. The keyhole concept in neurosurgery. World Neurosurg 2013;79(Suppl 2):S17.e9–13. DOI: 10.1016/j.wneu.2012.02.024.
4. Rohner D., Guijarro-Martínez R., Bucher P., Hammer B. Importance of patient-specific intraoperative guides in complex maxillofacial reconstruction. J Craniomaxillofac Surg 2013;41(5):382–90. DOI: 10.1016/j.jcms.2012.10.021.
5. Bryson E.O., Levine A.I. The simulation theater: a theoretical discussion of concepts and constructs that enhance learning. J Crit Care 2008;23(2):185–7. DOI: 10.1016/j.jcrc.2007.12.003.
6. Rehder R., Abd-El-Barr M., Hooten K. et al. The role of simulation in neurosurgery. Childs Nerv Syst 2016;32(1):43–54. DOI: 10.1007/s00381-015-2923-z.
7. Lai L., Morgan M.K. The impact of changing intracranial aneurysm practice on the education of cerebrovascular neurosurgeons. J Clin Neurosci 2012;19(1):81–4. DOI: 10.1016/j.jocn.2011.07.008.
8. Alaraj A., Charbel F.T., Birk D. et al. Role of cranial and spinal virtual and augmented reality simulation using immersive touch modules in neurosurgical training. Neurosurgery 2013;72(Suppl 1):115–23. DOI: 10.1227/NEU.0b013e3182753093.
9. Aboud E., Al-Mefty O., Yaşargil M.G. New laboratory model for neurosurgical training that simulates live surgery. J Neurosurg 2002;97:1367–72. DOI: 10.3171/jns.2002.97.6.1367.
10. Mashiko T., Otani K., Kawano R. et al. Development of three-dimensional hollow elastic model for cerebral aneurysm clipping simulation enabling rapid and low cost prototyping. World Neurosurg 2015;83(3):351–61. DOI: 10.1016/j.wneu.2013.10.032.

ORCID of author / ORCID автора
M.J. Encarnacion Ramirez / М.Х. Энкарнасьон Рамирес: https://orcid.org/0000-0003-3541-0635

Conflict of interest. The author declares no conflict of interest.
Конфликт интересов. Автор заявляет об отсутствии конфликта интересов.

Financing. The study was performed without external funding.
Финансирование. Исследование проведено без спонсорской поддержки.

Article submitted: 21.10.2020. **Accepted for publication:** 16.03.2021.
Статья поступила: 21.10.2020. **Принята к публикации:** 16.03.2021.